State of California
Department of Fish and Wildlife

Memorandum

Date: January 25, 2017

To: Ms. Lynn Sadler
Deputy Director
California Department of Parks and Recreation

From: Sandra Morey, Deputy Director
Ecosystem Conservation Division

Subject: Risk Assessment for Carolina fanwort (*Cabomba caroliniana*)

In response to the August 26, 2014, letter from the Division of Boating and Waterways requesting risk assessments for five species of aquatic plants identified by the California Department of Parks and Recreation as potentially invasive, please find enclosed the California Department of Fish and Wildlife's (CDFW) risk assessment findings and determination regarding Carolina fanwort (*Cabomba caroliniana*). As required by the Harbors and Navigation Code (HNC), section 64.5, CDFW included in their assessment:

- Whether Carolina fanwort may obstruct navigation and recreational uses of waterways;
- Whether Carolina fanwort may cause environmental damage, including threats to the health and stability of fisheries, impairment to birds' access to waterways and nesting, roosting, and foraging areas, deterioration of water quality resulting from plant decay, and harm to native plants;
- Whether Carolina fanwort may cause harm to the state's economy, infrastructure, or other manmade facilities such as state water storage facilities and pumping operations, by increasing flood risk, threatening water supplies by blocking pumps, canals, and dams necessitating early control efforts; and
- Whether Carolina fanwort causes or is likely to cause any other harm to California's environment, economy, or human health or safety.

To ensure thorough consideration of the species' ecological characteristics and the specified impacts and threats, CDFW employed the U.S. Aquatic Weed Risk Assessment tool. As specified in HNC sec. 64.5, CDFW consulted with the California Department of Food and Agriculture, the California Department of Water Resources, the State Water Resources Control Board, the California Department of Pesticide Regulation, and the Office of Environmental Health Hazard Assessment to develop the risk assessment findings and determination.

As fully detailed within the enclosed risk assessment, CDFW concludes that Carolina fanwort should be considered an invasive aquatic plant that causes or is likely to cause economic or environmental harm or harm to human health in California.

In response to your July 13, 2016, request, CDFW staff is currently drafting the risk assessment of floating pennywort (*Hydrocotyle ranunculoides*).

If you have any questions regarding this risk assessment, or the other in process, please contact Ms. Martha Volkoff, Habitat Conservation Planning Branch, Invasive Species Program, at (916) 651-8658 or by email at martha.volkoff@wildlife.ca.gov.

Enclosure

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Aquatic Plant Risk Assessment

Carolina fanwort, *Cabomba caroliniana* A. Gray

January 24, 2017

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INTRODUCTION

The California Department of Parks and Recreation's Division of Boating and Waterways (DBW) is the lead agency of the state for the purpose of cooperating with other state, local, and federal agencies in identifying, detecting, controlling, and administering programs to manage, control, and when feasible, eradicate invasive aquatic plants in the Sacramento-San Joaquin Delta, its tributaries, and the Suisun Marsh. Harbors and Navigation Code §64.5 defines an "invasive aquatic plant" as an aquatic plant or algae species, including its seeds, fragments, and other biological materials capable of propagating that species, whose proliferation or dominant colonization of an area causes or is likely to cause economic or environmental harm or harm to human health. Per §64.5, for aquatic plant species that DBW believes may be invasive and desires to manage, control, or eradicate, DBW shall request that the California Department of Fish and Wildlife (CDFW) conduct a risk assessment to determine if the species causes or is likely to cause economic harm or environmental harm or harm to human health. The risk assessment shall be documented in a way that clearly describes the severity and types of impacts caused or likely to be caused by a plant species determined to be an invasive aquatic plant. CDFW shall report its findings to DBW within 60 days of completing the risk assessment.

DETERMINATION

In response to DBW's August 26, 2014 request, CDFW evaluated whether Carolina fanwort, *Cabomba caroliniana* (fanwort), should be considered an invasive aquatic plant in California. To make the determination, CDFW selected a quantitative assessment tool that evaluated aspects of the species' ecology, reproductive potential, dispersal mechanisms, competitive ability, actual and potential impacts (including impacts to navigation and recreation, the environment, economy, and human health as specified in Harbors and Navigation Code §64.5), and resistance to management. Based on this evaluation and the findings contained herein, CDFW, in consultation with California Department of Water Resources (DWR), State Water Resources Control Board (SWRCB), Department of Food and Agriculture (CDFA), Department of Pesticide Regulation (DPR), and Office of Environmental Health Hazard Assessment (OEHHA), and in concurrence with DWR, determines that Carolina fanwort is an invasive aquatic plant that causes, or is likely to cause, economic or environmental harm, or harm to human health in California.

CURRENT DISTRIBUTION

Fanwort is native to South America and either native or naturalized in the southeastern United States, from Florida west to Texas and north to Virginia (Fassett 1953; Wilson et al. 2007). Fanwort is now considered invasive in temperate and sub-tropical areas of North America (United States and Canada), Australia, Asia (China, Japan, and India), and Europe (the Netherlands), and has established in Malaysia, New Zealand, Papua New Guinea, New Caledonia, Belgium, France, Greece, Hungary, Serbia, and the United Kingdom (Oki 1994; Schooler 2008, Vukov et al. 2013; CABI 2015). In North America, fanwort is typically considered non-native northeast of Virginia and west of Texas (Fassett 1953). Because fanwort is a popular plant in the aquarium trade, most new populations are thought to have established as a result of dumped aquariums or escape from cultivation, either accidental or deliberate (Schooler et al. 2006; Wilson et al. 2007; June-Wells et al. 2012; McCracken et al. 2013). The exact timing of introduction into California is unknown, but fanwort was reportedly first collected in the western United States in 1962 near Astoria, Oregon (Wilson et al. 2007). Fanwort is now present in Washington, Oregon, and California, and has been documented in each of the following geographic provinces classified by the State Wildlife Action Plan (CDFW 2015): Central Valley and Sierra Nevada and Bay-Delta and Central Coast, including the East (San Francisco) Bay (Calflora 2016).

Fanwort is regulated as a noxious weed by the California Department of Food and Agriculture (CDFA 2016). In addition to California, fanwort is identified as invasive or regulated as noxious, restricted, or prohibited in the states of Maine, Vermont, New Hampshire, Connecticut, Massachusetts, Wisconsin, Idaho, and Washington (CISEH 2013; USDA 2016).

RISK ASSESSMENT

Fanwort was assessed using the U.S. Aquatic Weed Risk Assessment (USAqWRA) tool, which was modified for the United States by Gordon et al. (2012) from the New Zealand Aquatic WRA model (Champion and Clayton 2001). The USAqWRA functions as the aquatic alternative to the Australian WRA, which is widely accepted and applied, but inaccurately classifies nearly all aquatic species as invasive, thus requiring modification for the accurate assessment of aquatic plants (Gordon and Gantz 2011). The USAqWRA has been tested for accuracy and validated under the environmental conditions of the United States and is the only assessment tool developed for the United States that maximizes accuracy for aquatic plants and incorporates all of the factors outlined in Harbors and Navigation Code §64.5.

The USAqWRA defines non-invaders as having no evidence of establishment outside of cultivation (in non-native ranges). Minor invaders are defined as species that have established in non-native ranges, but with no described ecological impacts. Major invaders are defined as having established in non-native ranges, and having documented, negative ecological impacts. Species are categorized using a scoring system of <31 (non-invaders), 31 – 39 (evaluate further), and >39 (major invaders). Gordon et al. (2012) determined that using the threshold score of 39 to distinguish major invaders from both minor and non-invaders maximized overall accuracy of the assessment tool at 91%.

CDFW conducted a thorough search of peer-reviewed journals and government publications to accurately complete the assessment. The resulting evaluation of fanwort invasiveness (Appendix A) produced a score of 75, predicting fanwort to be a "major invader" of the Sacramento-San Joaquin Delta. The findings using the USAqWRA model are summarized below, along with additional findings relevant to assessing potential impacts.

ECOLOGY

Fanwort is a submerged, perennial macrophyte that, in tropical to sub-tropical climates, grows throughout the year unless limited by water level fluctuations. In temperate climates, including in California, fanwort exhibits an annual growth pattern; when water temperatures drop below 13 °C (55.4 °F), fanwort stems defoliate and develop turion-like tips (Mackey 1996; Wilson et al. 2007; Mikulyuk and Nault 2009; Bickel and Schooler 2015). Although stems are normally buoyant and prone to fragmentation, as seasonal water temperatures drop stems sink and become especially brittle and susceptible to fragmentation (Mackey 1996; Wilson et al. 2007; Mikulyuk and Nault 2009). Stems and fragments lie dormant through the winter, usually buried in mud, though in warm winters, dieback may not occur (Mackey and Swarbrick 1997; Wilson et al. 2007; Mikulyuk and Nault 2009; Bickel and Schooler 2015). Stem fragments remain green throughout winter, even under ice in cold climates, and resume growth when spring water temperatures warm to 13 °C (55.4 °F) (Hogsden et al. 2007; Wilson et al. 2007). In the spring, stems grow to the surface very rapidly, growing up to 5 cm per day and reaching up to 10 m in length; each root mass produces between 3 and 40 stems (Mackey and Swarbrick 1997; Wilson et al. 2007). Leaves are typically submerged and covered in trichomes, which produce a mucous covering the entire plant; flowering shoots produce small floating leaves as well (Ørgaard 1991; Mackey and Swarbrick 1997). Fanwort displays a high level of phenotypic variation thought to be based on water temperature and available light (Mackey and Swarbrick 1997). Variation in leaf color from green to purplish to red-brown was examined and found to have no genetic basis, but three varieties of fanwort are now recognized based on flower color: *C. caroliniana* var. *caroliniana* (white flowers; the variety found in California), *C. caroliniana* var. *pulcherrima* (purple flowers), and *C. caroliniana* var. *flavida* (yellow flowers) (Wain et al. 1983; Ørgaard 1991; Rosatti 2016).

Fanwort is found in a variety of freshwater habitats, with ideal conditions found in stagnant or slow-flowing waters of lakes, ponds, canals, drains, swamps, streams, and rivers (Wain et al. 1983; Hogsden et al. 2007; Wilson et al. 2007). However, in the southern United States large populations of fanwort are occasionally found in fast-flowing rivers (Wilson et al. 2007). Fanwort usually occurs in shallow water from 1 – 3 m deep, with maximum depth typically reported as 10 m (Mackey 1996; Wilson et al. 2007; Mikulyuk and Nault 2009). In deep water, fanwort is sometimes found free-floating, but is usually shallowly rooted in silty substrate; fanwort tolerates sandy to rocky substrate, though growth is reduced (Tarver and Sanders 1977; Mackey and Swarbrick 1997; DiTomaso and Healy 2003; Wilson et al. 2007). Fanwort grows in oligotrophic to eutrophic waters; its pH tolerance is variably reported in the literature, but it is generally accorded to grow best in acidic waters with a pH ranging from 4 – 6 and experiences growth inhibition and loss of leaves in waters with a pH above 8 (Mackey and Swarbrick 1997; Wilson et al. 2007; Mikulyuk and Nault 2009). The major factors limiting fanwort distribution are temperature, pH, total phosphorous, high calcium levels, and salinity (Jacobs and MacIsaac 2009; Poirrier et al. 2010; James 2011; Bickel and Schooler 2015). In Louisiana, fanwort is found at salinities up to 0.4 ppt and is apparently limited by salinities above 0.5 ppt (Poirrier et al. 2010). Fanwort grows well in low light conditions (Santos et al. 2012), and grows best in moderate to heavy turbidity, perhaps because of higher nutrient availability in the water column, which the plant absorbs through shoots, leaves, and stems (Mackey 1996; Mackey and Swarbrick 1997; Wilson et al. 2007; Mikulyuk and Nault 2009).

REPRODUCTIVE POTENTIAL

Fanwort reproduces both sexually and vegetatively, although successful sexual reproduction is rare in its invasive range and only documented within a single population in Australia (Schooler et al. 2006; de Lima et al. 2014). When seeds are produced in temperate areas, they typically have been found to be sterile (Ørgaard 1991; Bickel and Schooler 2015); germination rates are low in its native, sub-tropical range as well (≤ 20%) (Tarver and Sanders 1977; Ørgaard 1991; Mackey and Swarbrick 1997). Growth and flowering occur year-round when water temperatures are within the optimal growth range of 13 – 27 °C (55.4 – 80.6 °F) (Wilson et al. 2007); in California, fanwort flowers from May to September, though populations are sterile (Calflora 2016). Fruits are apocarpous and, if seeds are produced, contain 3 seeds per fruit (Ørgaard 1991; Mackey and Swarbrick 1997). Fruits drop to the substrate and release seeds by decomposition; if viable seeds are produced they typically germinate in 5 – 10 weeks, but are viable for up to 2 years as long as the seed remains moist (Tarver and Sanders 1977; Ørgaard 1991; Mackey and Swarbrick 1997). Vegetative reproduction is often reported as fragmentation of rhizomes (e.g., Ørgaard 1991), but fanwort does not form true rhizomes (Mackey and Swarbrick 1997; de Lima et al. 2014). Instead, fanwort forms stems which may be erect or prostrate and fragment easily during the growing season and, in temperate climates, especially as water temperatures drop in the fall (Mackey and Swarbrick 1997). A fragment of stem containing a single pair of leaves can give rise to a new plant (Mackey and Swarbrick 1997).

Dispersal Mechanisms

Although initial introductions are typically attributed to aquarium dumping, escape from water gardens, or deliberate introduction by commercial growers to form a source population (Schooler et al. 2006; Wilson et al. 2007; June-Wells et al. 2012; McCracken et al. 2013), fanwort introductions are also the result of long-distance dispersal by recreational watercraft and trailers (McCracken et al. 2013; Bickel 2015). Though individual fragments of fanwort dry out and lose viability relatively quickly during overland transport on a watercraft or trailer, small clumps have been shown to survive 42 hours of transport (Bickel 2015). Once within a waterbody, fanwort typically disperses via fragmentation; stems are buoyant during the growing season and are easily transported by wind and water currents (Mackey and Swarbrick 1997; DiTomaso et al. 2013; de Lima et al. 2014). Fanwort is also transported by waterfowl, either as seeds or fragments on plumage (Mackey and Swarbrick 1997; Schooler et al. 2006; CABI 2015). Although prohibited in many states, fanwort remains popular in the aquarium trade and is widely available, continuing the risk of introduction from this pathway (Cohen et al. 2007; June-Wells et al. 2012).

Competitive Ability

Fanwort is capable of establishing in existing native and non-native vegetation (Zhang et al. 2003; ISSG 2006; Capers et al. 2007), as well as in disturbed areas (Zhang et al. 2003). Fanwort mats at the water surface can reduce available light reaching the sediment surface to zero (Hogsden et al. 2007) and fanwort has been shown to produce allelopathic compounds in bioassay experiments; these factors may reduce germination of emergent plants and are thought to allow fanwort to displace other submerged plants (Elakovich and Wooten 1989; Mackey 1996; Lyon and Eastman 2006; Schooler et al. 2006). In most of its invasive range, fanwort forms monospecific beds, though some other native and non-native plants are able to coexist with it, and *Egeria densa* is sometimes able to outcompete it (Mackey and Swarbrick 1997; Lyon and Eastman 2006).

Realized and Potential Impacts

Obstruction of Navigation and Recreation

Fanwort's stems can reach 10 m in length, fill the entire water column, and form mats at the surface (Wilson et al. 2007). Dense infestations, capable of reaching over 200 plants/m^2, clog waterbodies, obstructing navigation and recreational activities (Schooler et al. 2006; Wilson et al. 2007). Boat propellers and paddles easily tangle in the long stems, impeding movement and producing stem fragments capable of forming new plants (Schooler et al. 2006). Fishing gear also tangles easily in mats of fanwort, and has resulted in decreased revenue and closure at fishing camps in the southeast United States (Mackey and Swarbrick 1997). Swimmers, divers, water skiers, and other in-water recreationalists are at risk of becoming tangled in the long, thick stems, which increases drowning hazards and makes recreation sites less appealing. Fanwort also fouls and discolors water, decreasing the appeal of recreation in infested areas. The obstruction of navigation and impacts to recreation have led to reduced tourism in fanwort-infested areas (Schooler et al. 2006).

Environmental Effects

Water quality – Fanwort alters water quality throughout the year. During the growing season, fanwort can increase local oxygen concentration and remove excess nutrients from the water, although dense growth locally decreases oxygen levels through stagnation (Mackey and Swarbrick 1997). During early winter, decomposition of foliage can result in severe deoxygenation and increased nutrient loading, altering the nutrient cycle, particularly of manganese (Mackey and Swarbrick 1997). Fanwort also fouls and discolors water and alters the pH and organic content of water and soil (Larson et al. 2016).

Native plants – Fanwort often forms monospecific stands in its non-native range (Lyon and Eastman 2006; Hogsden et al. 2007; Wilson et al. 2007). Evidence suggests fanwort displaces other plants by producing allelopathic compounds which limit the growth of both aquatic and, to a lesser extent, terrestrial plants; in addition, fanwort significantly reduces available light for submerged and germinating emergent aquatic plants (Elakovitch and Wooten 1989; Schooler et al. 2006; Hogsden et al. 2007). In New England and Canada, where fanwort is recognized as an invasive aquatic weed, several studies have found that dense stands of fanwort reduce native plant abundance and distribution (Lyon and Eastman 2006; Capers et al. 2007; Hogsden et al. 2007). Fanwort is able to invade habitats supporting dense, vigorous growth of many native plant species (Capers et al. 2007). High-density populations of fanwort typically form monospecific stands exhibiting a high degree of spatial separation from native and non-native aquatic plants (Lyon and Eastman 2006). As of 2008, fanwort was sparsely present in the Sacramento-San Joaquin Delta (Delta) and interspersed with native and non-native aquatic plants (Santos et al. 2011). However, Rosatti (2016) notes that fanwort is spreading rapidly in the Delta and is expected to become widely distributed. In its native range, fanwort occupies a much narrower realized niche, from 2 – 4 m water depth, rarely forming dense, monospecific, or large stands, compared to its non-native range in which fanwort is found from 1 – 10 m water depth and has a tendency to monopolize large areas with dense cover; in its native range, fanwort is co-dominant with other aquatic plants depending on season, climate, and population age (Schooler et al. 2006).

Birds and waterfowl – Fanwort outcompetes and replaces both native and non-native aquatic plants that serve as a food source for waterfowl (Lyon and Eastman 2006; Hogsden et al. 2007; Wilson et al. 2007). There is discrepancy in the literature as to whether fanwort is utilized as a food source by birds and other wildlife, though if so, it is likely not an important food source for birds and waterfowl, even in its native range (Martin and Uhler 1939; Wilson et al. 2007). In its non-native range, its value as an alternative food source is unknown (Wilson et al. 2007). Due to its submersed nature, fanwort is not recognized for restricting birds' access to roosting, foraging, or nesting habitats.

Health and stability of fisheries – The effect of fanwort infestation on fisheries is largely unknown (Wilson et al. 2007). There is evidence that fanwort provides cover for juvenile fishes and can benefit their populations; however, this has largely been found in the southeastern United States, where fanwort is either native or has been naturalized for hundreds of years (Ørgaard 1991; Mackey and Swarbrick 1997). In Queensland, Australia, fanwort is thought to negatively affect endangered Mary River cod populations, though the mechanism is unknown (Schooler et al. 2006). In Canada, fanwort has been shown to alter habitat structure and invertebrate (prey) communities, and is therefore expected to negatively affect native fish populations (Hogsden et al. 2007). In response to herbivory from invertebrates, fanwort exhibits a chemical defense that reduces its palatability and value as a food source; whether a similar response to herbivorous fish exists is unknown (Morrison and Hay 2011).

Other wildlife – In Queensland, Australia, populations of native platypus and water rats are lower in creeks infested with fanwort (Australian Department of the Environment and Heritage 2003). In its native or naturalized range in the southeastern United States, fanwort is an important food source of the Texas river cooter (*Pseudemys texana*), a freshwater basking turtle (Fields et al. 2003).

Economic, Infrastructure, or Man-made Facilities

Dense infestations of fanwort negatively affect the economy, infrastructure, and facilities. Fanwort clogs machinery at dams, including valves, pumps, and aerators, increasing maintenance costs and interfering with power generation (Schooler et al. 2006). For more than 100 years, fanwort has been one of the problematic weed species requiring management to keep the Panama Canal functional (Hearne 1966). Fanwort blocks drainage and irrigation canals, reducing water delivery for irrigation (Schooler et al. 2006). Dense growth of fanwort slows water velocities, increasing sedimentation rates and leading to increased risk of flooding (Larson et al. 2016). Fanwort's odorous and discoloring effects on water quality require increased treatment, raising costs up to 50 AUD ($37.91 USD) per megaliter (264,172 gal.) in Australia (Mackey 1996; Mackey and Swarbrick 1997). At Kasshabog Lake, Ontario, Canada, there is concern that lakefront property values will decrease due to the heavy infestation of fanwort in the lake (Wilson et al. 2009). Although not widely recognized as an agricultural weed, fanwort could become a major weed in Canadian wild rice fields (Larson et al. 2016); the Delta is an important rice-growing region in California where fanwort infestations in rice fields could have a significant economic impact. Aquaculture farms are also vulnerable to infestation by fanwort (Wilson et al. 2007).

Human Health

Seasonal dieback and decomposition of fanwort taints potable water supplies, resulting in discoloration and a foul odor that requires additional treatment of water before it can be distributed to consumers (Schooler et al. 2006; van Oosterhout 2009; GISD 2016). Heavy infestations clog waterways and increase water levels, which can lead to an increased risk of flooding (Mackey and Swarbrick 1997). Fanwort is also reported to create mosquito habitat in Queensland, Australia (QDAF 2016). The long, thick stems of fanwort present an additional threat to human health and safety, as swimmers and divers could easily become entangled in dense stands and drown (Mackey and Swarbrick 1997). In the United States, similar dense infestations of invasive, submerged aquatic vegetation (Eurasian watermilfoil, *Myriophyllum spicatum*, and Hydrilla, *Hydrilla verticillata*) have been linked to 12 drownings in 5 states, including California, between 1990 and 2007 (CAST 2014).

RESISTANCE TO MANAGEMENT

Fanwort can be controlled by hand removal, mechanical harvesting, water drawdowns, shading, biological control agents, and herbicides (Mackey and Swarbrick 1997; Schooler et al. 2006; Wilson et al. 2007; DiTomaso et al. 2013). However, managers recognize fanwort as a difficult aquatic weed to control (Mackey and Swarbrick 1997; Wilson et al. 2007). Hand removal can be effective, but is time-consuming and impractical over large areas with dense cover, especially in deep areas, which require divers. Mechanical harvesting and, to a lesser degree, hand removal produce fanwort fragments that can float downstream, creating new populations and adding to existing ones (Wilson et al. 2007). DiTomaso et al. (2013) report water drawdown as an effective control mechanism for fanwort. Seeds are especially sensitive to drying, so drawdowns in sexually reproducing populations are most effective (Tarver and Sanders 1977). Drawdowns also help to control populations that do not produce viable seed, such as in California (e.g., Dugdale et al. 2013). If drawdowns are used as a control mechanism, particularly in populations that do not reproduce sexually, the substrate must be allowed to dry fully beneath mounds of fanwort, or regrowth will occur (Dugdale et al. 2013). Performing drawdowns in hot weather can significantly reduce the time required for the drawdown to be effective (Dugdale et al. 2013). Herbicides can also be utilized in combination with drawdowns (Mackey and Swarbrick 1997).

Complete shading is an effective control measure, but requires an extended treatment period. In one Australian experiment, 99% shading for 120 days was required to reduce biomass to zero (Schooler 2008). At a stocking rate of 17 – 30 fish per hectare, effective biological control has been achieved by grass carp in Florida and Arkansas; however, while grass carp will consume fanwort, it is not a preferred food and use of grass carp in open-water systems is prohibited in California (Mackey and Swarbrick 1997; Hanlon et al. 2000; Wilson et al. 2007).

Chemical control typically involves use of herbicides, though using lime to increase pH beyond fanwort's tolerance has been effective in laboratory trials (James 2011). However, this requires a significant pH increase that may also negatively affect other aquatic plants depending on their photosynthetic mechanism, including some Delta natives (James 2011). There are multiple options for chemical control of fanwort, including diquat, endothall, 2,4-D, and fluridone (Wilson et al. 2007; DiTomaso et al. 2013). Of these herbicides, fluridone and, to a limited extent, 2,4-D are currently utilized by DBW in their treatment of aquatic invasive plants in the Delta (L. Ramos, DBW, personal communication). However, effects of herbicides on fanwort are often inconsistent, appear to be reduced in open-water systems, and are generally more effective on actively growing plants (Mackey 1996; Nelson et al. 2002; Wilson et al. 2007; Mikulyuk and Nault 2009). When herbicides are effective, they typically require re-treatment and often the integration of alternative control methods (Wilson et al. 2007). In the United States, recent effective herbicide control of fanwort has most often utilized fluridone, though a high concentration and long treatment time (20 µg/L for 84 days) was required for an 80% reduction in biomass (Nelson et al. 2002).

Assessing fanwort infestations may be difficult due to its submerged growth habit and similarities in appearance with other submerged non-native and native aquatic plants found in the Delta, including Eurasian watermilfoil (*Myriophyllum spicatum*), parrotfeather (*Myriophyllum aquaticum*), marshweed (*Limnophila* x *ludoviciana*), coontail (*Ceratophyllum demersum*), whorled milfoil (*Myriophyllum verticillatum*), northern watermilfoil (*Myriophyllum sibiricum*), and white waterbuttercup (*Ranunculus aquatilis*) (DiTomaso and Healy 2003; Wilson et al. 2007; Mikulyuk and Nault 2009). Inconsistent susceptibility of fanwort to herbicides and difficulties associated with other control mechanisms, as well as interspersion of fanwort with other species not authorized for treatment in the Delta pose some challenges to implementation of management efforts.

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APPENDIX A: Risk Assessment of Carolina fanwort, *Cabomba caroliniana* A. Gray

Species: Carolina fanwort; *Cabomba caroliniana* A. Gray					
	Question - USAqWRA	**Score and guidance – USAqWRA**	**Score**	**Justification**	**Reference**
1.1	Temperature tolerance	**(0-3)** Score 3 if maintains photosynthetic tissue and summer growth form throughout winter, 2 if dies back to tuber/bulb/rhizome (or similar structure) during winter, 1 if adult plants completely die but viable seeds remain. Use a climate matching tool if direct evidence is not available. Default = 1 for annual species.	2	Grows in water temperatures 13 - 27 °C. When water temperature drops below this in temperate climates, fragments and forms turion-like structures to overwinter.	Hogsden et al. 2007; Wilson et al. 2007; Bickel and Schooler 2015
1.2	Range of habitat	**(1-3)** Score 3 if able to grow from water to dry land, 2 if water to wetland, or from shallow to deep (>5 m) water, 1 narrow range.	2	Grows from shallow water to 10 m deep. Prefers 1 - 3 m deep water.	Wilson et al. 2007
1.3	Water/ substrate type tolerance	**(1-2)** Score 2 if tolerant of sandy to muddy (or peaty) substrate, or oligotrophic to eutrophic waters, 1 if restricted by either. Default = 1 if no information is available.	2	Prefers silty soil, but tolerates sandy or rocky substrates, or free-floating. Grows readily in oligotrophic to eutrophic conditions.	Tarver and Sanders 1977; DiTomaso and Healy 2003; Wilson et al. 2007
1.4	Water clarity tolerance	**(0-1)** Score 1 if unaffected by water clarity (i.e. floating or emergent, or submergents tolerant of very low light levels, such as *Myriophyllum spicatum* and *Hydrilla verticillata*), 0 if affected by water clarity.	1	Tolerates turbid conditions and low light levels.	Zhang et al. 2003; Lyon and Eastman 2006
1.5	Salinity tolerance	**(0-1)** Score 1 if species can tolerate saline conditions, 0 if not. Habitat information can be used to determine a score of 0 if species is only found to occur in freshwater habitats.	0	Appears to be limited by salinity higher than 0.5 ppt.	Poirrier et al. 2010
1.6	pH tolerance	**(0-1)** Score 1 if tolerant of both acidic and basic pH or no information is available, 0 if restricted to neutral, basic, or acidic pH.	1	Grows in waters with pH of 4-8.	Wilson et al. 2007; James 2011
1.7	Water level fluctuation - tolerates periodic flooding/ drying	**(0-3)** Score 3 for species which have evidence of tolerating periodic flooding/drying with a specified time period longer than 1 month (e.g., "months"; "X months", "winter flooding"), 2 for evidence of tolerance of flooding/drying over a period of days/a couple of weeks, 1 for species that die back during periods of flooding/drying, and 0 for species that do not tolerate flooding/drying.	3	Plants naturally form mounds when water levels drop. Mounds and substrate beneath them must dry completely to prevent regrowth; this can take months, depending on temperature and humidity.	Dugdale et al. 2013

Species: Carolina fanwort; *Cabomba caroliniana* A. Gray					
	Question - USAqWRA	**Score and guidance – USAqWRA**	**Score**	**Justification**	**Reference**
2.1	Lotic - Rivers, streams, drains, or other flowing waters, including their margins	**(0-3)** Score 3 if major weed (reaches high density and dominates plant community), 2 if minor weed (common, but rarely or never dominant), 1 if present but not weedy, 0 if absent.	3	Dominates in slow-flowing streams and rivers; in Texas, grows abundantly in the fast-flowing headwaters of the San Marcos River.	Ørgaard 1991; Zhang et al. 2003;Wilson et al. 2007
2.2	Lentic - Ponds, lakes and other standing waters, including their margins	**(0-3)** Score 3 if major weed (reaches high density and dominates plant community), 2 if minor weed (common, but rarely or never dominant), 1 if present but not weedy, 0 if absent.	3	Dominates in standing water.	Wain et al. 1983; Hogsden et al. 2007; Wilson et al. 2007
2.3	Swamp, marsh, bog, or other wet areas not covered by 2.1 or 2.2	**(0-3)** Score 3 if major weed (reaches high density and dominates plant community), 2 if minor weed, 1 if present but not weedy, 0 if absent.	3	Dominates in stagnant waters.	Hogsden et al. 2007; Wilson et al. 2007
2.4	Establishment - into existing vegetation	**(-5, -3, 0)** Score 0 if able to invade unmodified vegetation, -3 if the species can only colonize certain types of vegetation (e.g., turf-forming shoreline vegetation), -5 if there is no evidence that the species can move into intact vegetation. Default = 0 if there is evidence of establishment, but no specific information about level of invasion into existing vegetation and/or type of vegetation being invaded. Default = -3 for species that have not naturalized outside of their native range.	0	Establishes into existing native and non-native vegetation.	Zhang et al. 2003; ISSG 2006; Capers et al. 2007
2.5	Establishment - into disturbed vegetation	**(0, 1, 5)** Score 5 if able to aggressively colonize following vegetation clearance, newly constructed waterbodies or nutrient enrichment, 1 if the species grows in disturbed areas, but there is no other information, 0 if there is no evidence of establishment in disturbed areas. Information from either the native or introduced range may be used to answer this question. Default = 1 for no information.	5	Rapidly establishes in disturbed areas.	Zhang et al. 2003
3.1	Competition - between growth form	**(0, 1, 2)** Score 2 if species forms dense stands that are documented to displace other growth forms (submersed, floating, emergent), 1 if some suppression, 0 if no displacement. Default = 0 if species has been in the trade globally for >30 years and there is no information about the species displacing other growth forms.	2	Occupies entire water column, shading out other submerged plants and preventing germination of emergent plants. Displaces other aquatic plants, possibly partly through allelopathy.	Elakovich and Wooten 1989; Lyon and Eastman 2006; Schooler et al. 2006

Species: Carolina fanwort; *Cabomba caroliniana* A. Gray					
	Question - USAqWRA	Score and guidance – USAqWRA	Score	Justification	Reference
4.1	Dispersal outside catchment by natural agents (e.g. birds, wind)	**(0, 1, 3, 5)** Score 5 if species (including seeds, rhizomes, fragments etc.) well adapted, and likely to be frequently dispersed, by natural agents, 3 if transport by natural agents is possible but uncommon, 1 if propagule could be spread in bird crop, 0 if no, or extremely low, likelihood of dispersal by natural agents (e.g., *Hydrilla* is scored 1 because its turions can survive passage through duck guts, an agent of dispersal, but this is believed to happen rarely).	3	Stem fragments and seeds may be transported on waterfowl plumage or in mud encrusting the feet of waterbirds.	Ørgaard 1991; Mikulyuk and Nault 2009
4.2	Dispersal outside catchment by accidental human activity	**(1, 2, 3)** Score 3 if major pathway, seeds/fragments adapted for easy transportation (e.g., via boat/trailer, fishing gear), 2 if the species is a floating plant or a macrophyte, but no explicit mention of high spread in the literature, 1 not mentioned, not likely to be spread by human activity based on growth form and life history. Default = 1 if no information is available.	3	Stem fragments are often transported via boat/trailer; clumps can survive long distance transport.	Jacobs and MacIsaac 2009; Bickel 2015
4.3	Dispersal outside catchment by deliberate introduction	**(0-1)** Score 1 if species is desirable to humans (e.g., or used for medicinal, food, ornamental, restoration, etc. purposes in the U.S. or elsewhere). If species is not used or no information exists, score should be 0.	1	Fanwort is an important aquarium plant and has been deliberately introduced to form source populations for trade.	Schooler et al. 2006; Wilson et al. 2007; June-Wells et al. 2012; McCracken et al. 2013
4.4	Effective spread within waterbody/ catchment	**(0-1)** Score 1 for extensive spread within a waterbody or among waterbodies, 0 for no spread. Occurrence along streams or riverbanks or in rivers can be used as evidence, as well as evidence of water dispersal. Do not answer if no information is available.	1	Readily spreads from dispersed stem fragments.	McCracken et al. 2013
5.1	Generation time (time between germination of an individual and the production of living offspring, not seeds or other dormant structures)	**(1, 2, 3)** Score 3 if rapid (reproduction in first year and >1 generation/year), 2 if annual or produces one generation every year including the first year, 1 if not reproductively mature in the first year. Default = 1 if no information is available.	3	Reproduction is primarily asexual, via stem fragmentation. Stems readily fragment beginning immediately after establishment. A new plant can form from a fragment containing one node and a pair of leaves.	Tarver and Sanders 1977; Schooler et al. 2006

Species: Carolina fanwort; *Cabomba caroliniana* A. Gray					
	Question - USAqWRA	**Score and guidance – USAqWRA**	**Score**	**Justification**	**Reference**
6.1	Seeding ability - quantity	**(0-3)** Score 3 if >1000 seeds/plant/year, 2 100-1000, 1 <100 and/or evidence that seed are produced (in native or introduced range), 0 if seed not produced.	0	In the introduced range, seeds are not produced, or, if produced, are not typically viable. Three seeds per fruit are produced in the native range.	Mackey and Swarbrick 1997; Schooler et al. 2006; de Lima et al. 2014
6.2	Seeding ability - viability/ persistence	**(0-2)** Score 2 if highly viable for >3 years, 1 low viability or evidence of seed production with no information on viability, 0 no viable seeds.	0	In the invasive range viable seed production is uncommon.	Mackey and Swarbrick 1997
7.1	Vegetative reproduction	**(0, 1, 3, 5)** Score 5 for naturally fragmenting from rhizomes, stolons, or other vegetative growth into tissue capable of producing new colonies (e.g., *Egeria densa*), 3 if produces rhizomes/stolons, but there is no other information about the formation of new colonies elsewhere, 1 for clump-forming by vegetative spread, 0 for no vegetative spread.	5	Stem readily fragments; this is the primary form of reproduction, even in sexually reproducing populations.	DiTomaso et al. 2013; de Lima et al. 2014
8.1	Physical - water use, recreation	**(0-2)** Score 2 for major nuisance, 1 for minor nuisance. Default = 0 if the species has not naturalized outside of its native range.	2	Infests rivers and lakes, forming dense beds in the shallows that impede recreation.	Zhang et al. 2003; Wilson et al. 2007
8.2	Physical - access	**(0-2)** Score 2 for major nuisance, 1 for minor nuisance. Default = 0 if the species has not naturalized outside of its native range.	2	Preferentially colonizes shallow waters near shore; dense beds impede access to waters.	Zhang et al. 2003; Wilson et al. 2007
8.3	Physical - water flow, power generation	**(0-2)** Score 2 for major nuisance, 1 for minor nuisance. Default = 0 if the species has not naturalized outside of its native range.	2	Clogs drainage canals and interferes with power generation.	Schooler et al. 2006; Wilson et al. 2007; WA DOE
8.4	Physical - irrigation, flood control	**(0-2)** Score 2 for major nuisance, 1 for minor nuisance. Default = 0 if the species has not naturalized outside of its native range.	1	Clogs irrigation canals.	WI DNR 2015
8.5	Aesthetic - visual, olfactory	**(0-2)** Score 2 for both visual and odor problems, 1 either, 0 neither or no mention of these impacts. Surface matting of macrophytes scores 1 for visual impact.	2	Forms mats on the surface; water in infested areas becomes dark and foul-smelling.	Larson et al. 2016

Species: Carolina fanwort; *Cabomba caroliniana* A. Gray					
	Question - USAqWRA	**Score and guidance – USAqWRA**	**Score**	**Justification**	**Reference**
9.1	Reduces biodiversity	**(0, 1, 3, 5)** Score 5 for extensive monospecific stands, 3 for species that become dominant, 1 for small monospecific stands, and 0 if species does not become dominant over other species. Default = 0 for this question if species has been in the trade globally for >30 years and no information is found or if the species is not naturalized outside of its native range.	5	Forms large, monospecific stands.	Lyon and Eastman 2006; Hogsden et al. 2007; Wilson et al. 2007
9.2	Reduces water quality	**(0, 1, 3)** Score 3 if evidence that this species causes deoxygenation (e.g., through extensive growth in shallow water) or other water quality loss (e.g., loss of water clarity because of high decomposition rates continuously during the growing season), 1 if deoxygenation or other water quality loss is likely based on seasonal growth cycles (e.g., macrophyte that gets to high density and dies off at end of summer), 0 otherwise. Default = 0 for this question if species has been in the trade globally for >30 years and no information is found or if the species is not naturalized outside of its native range.	3	Negatively affects water quality all year through deoxygenation and changing nutrient regimes; seasonal decomposition causes nutrient spiking and increases deoxygenation.	Wilson et al. 2007; CABI 2015
9.3	Negatively affect physical processes	**(0, 2)** Score 2 if species alters hydrology (e.g., increases the chance of flooding) or substrate stability (e.g., increases amount of sediment erosion or deposition), or other physical processes, 0 if the species has no history of modifying physical processes. Default = 0 for this question if species has been in the trade globally for >30 years and no information is found or if the species is not naturalized outside of its native range.	2	Dense populations clog waterways and can cause flooding; dense mats may increase sedimentation.	Mackey and Swarbrick 1997; Larson et al. 2016
10.1	Human health impairment (e.g. drowning, poisonous, mosquito habitat)	**(0-2)** Score 1 for one effect, 2 for 2 or more effects.	2	May increases risk of drowning by entangling swimmers; provides habitat for mosquito larvae.	Schooler et al. 2006; QDAF 2016
10.2	Weed of agriculture, including crops, livestock and aquaculture	**(0-1)** Score 1 if a problem agricultural weed, 0 if no evidence that it is an agricultural weed, or if evidence states that species is in agricultural areas but not problematic.	0	No evidence as an agricultural weed, but could possibly become a problem in commercially important rice fields.	Larson et al. 2016

Species: Carolina fanwort; *Cabomba caroliniana* A. Gray					
	Question - USAqWRA	**Score and guidance – USAqWRA**	**Score**	**Justification**	**Reference**
11.1	Management - Ease of management implementation	**(0-2)** Score 2 if accessibility to weed is difficult, e.g. dense tall impenetrable growths or growing in habitats that are difficult to access by roads or waterways (e.g., swamps). For species that have naturalized outside of their native range, default = 0-2 based upon evidence about habitat and/or growth form if there is no direct evidence from the literature. Default = 0 if species has not naturalized outside of its native range and has been in the trade globally for >30 years.	2	Dense growth capable of obstructing navigation and tangling boat propellers; sometimes grows in difficult-to-reach areas such as swamps.	Schooler et al. 2006; Wilson et al. 2007
11.2	Management - Recognition of management problem	**(0-1)** Score 1 if difficult to assess weed, e.g., submersed; looks like another species. For species that have naturalized outside of their native range, default to a score between 0-1 based upon growth form evidence if there is no direct evidence from the literature. Default = 0 if species has not naturalized outside of its native range and has been in the trade globally for >30 years.	1	Submerged; similar in appearance to Eurasian watermilfoil, coontail, and several other native and non-native species that occur in the Delta.	DiTomaso and Healy 2003; Wilson et al. 2007; Mikulyuk and Nault 2009
11.3	Management - Scope of control methods	**(0, 1, 2)** Score 2 if no control method, 1 if only one control option. If species has naturalized outside of its native range, and there is no direct evidence for either 11.1 or 11.2, do not answer if there is no information. If there is direct evidence for 11.1 and/or 11.2, default to 0 if there is no information for questions 11.3 – 11.6.	0	Multiple control options, including mechanical, biological, chemical, and water drawdown.	DiTomaso et al. 2013
11.4	Management - Control method suitability	**(0-1)** Score 1 if control method not always acceptable, e.g., grass carp, unregistered herbicide. If species has naturalized outside of its native range, and there is no direct evidence for either 11.1 or 11.2, do not answer if there is no information.	1	Mechanical control often exacerbates the problem by producing fragments; possible biological control agents include grass carp.	Schooler et al. 2006; DiTomaso et al. 2013
11.5	Management - Effectiveness of control	**(0, 1, 2)** Score 2 if ineffective, 1 if partial control. If species has naturalized outside of its native range, and there is no direct evidence for either 11.1 or 11.2, do not answer if there is no information.	1	Partial control possible, but many herbicides are ineffective and mechanical control increases fragmentation.	Schooler et al. 2006
11.6	Management - Duration of control	**(0, 1, 2)** Score 2 if no control, 1 if control for 3+ months. If species has naturalized outside of its native range, and there is no direct evidence for either 11.1 or 11.2, do not answer if there is no information.	1	Depending on the method, control possible from weeks to one year.	Mackey and Swarbrick 1997

Species: Carolina fanwort; *Cabomba caroliniana* A. Gray					
	Question - USAqWRA	**Score and guidance – USAqWRA**	**Score**	**Justification**	**Reference**
12.1	Problem in other countries	**(0, 1, 3, 4, 5)** Score 5 if species has been reported to be a widespread problem (i.e., a harmful weed in many other countries), 4 if species has been reported to be a harmful weed in 5 or fewer countries, 3 if species has been reported to be a widespread adventive (but not a harmful weed) in many other countries, 1 if species has been reported to be adventive in 5 or fewer countries, 0 if not adventive elsewhere.	5	Problematic weed in Australia, Canada, China, Japan, India, and the Netherlands. Present as a weed in many other countries.	Schooler 2008; CABI 2015
		USAqWRA Score	**75**		